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Coefficient of performance (COP) analysis of geothermal district heating systems (GDHSs): Salihli GDHS case study

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ABSTRACT

The purpose of this survey is about to analyze the heating coefficient of performance (COP) of geothermal district heating systems. Actual system data are taken from the Salihli GDHS, Turkey. The collected data are quantified and illustrated in tables, particularly for a reference temperature for comparison purposes. In this study, firstly energy and COP analysis of the GDHSs is introduced and then Salihli GDHS coefficient of performance results is given as a case study. Moreover, this paper offers an interesting empirical study of certain geothermal systems.

Contents

1. Introduction

There is a growing global demand for thermal energy production from geothermal reservoirs. Most of the produced thermal water energy from geothermal reservoirs has been used for heating purposes in Turkey. It is known that geothermal district heating systems have a number of positive social characteristics, because they are simple, safe, and adaptable systems. In addition, it is well known that geothermal energy has negligible emissions of CO_2, SO_x, NO_x, and particulates. These features are compatible with sustainable growth of global energy supplies in both developed and developing countries, geothermal energy are an attractive option to replace fossil and fissile fuels [1].

Utilization of geothermal energy for central heating purposes in Turkey has increased since 1964 when the first geothermal space heating application was realized in a hotel in Gonen, Balikesir. By the end of 2004 ten city-based geothermal district heating systems installed with a total capacity about 700 MW in Turkey. City-based geothermal district heating applications started in 1987 in Turkey. However, to date, their development has been relatively low [2].

Therefore, a lot of studies related to the geothermal district heating systems and their energetic and exergetic performance analysis have been made in Turkey in the last five years. However, according to author's present knowledge no any examination of the coefficient of performance analysis of GDHSs has been analyzed in open literature. The operation and thermodynamics efficiencies of Salihli geothermal field are monitored in author's companion works.

In this work, the author extend the previous work done on Salihli GDHS TUBITAK research Project by considering two years monitoring performance results, author also undertake a case study to investigate how varying heating COP value considered affect ambient temperature of GDHS and to estimate a COP which is

Abbreviation: GDHS, geothermal district heating system.

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Nomenclature

COP	coefficient of performance
$\dot{E}$	energy rate (kW)
h	specific enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
n	number of wellhead (n = 1,2,. . .,5)
$\dot{W}$	work rate (or power) (kW)

Greek letters

η	energy (First Law) efficiency (%)

Subscripts

d	discharged
HE	heat exchanger
i, k	successive number
r	reinjected thermal water
sys	system
Tot	total
w	well-head, thermal water
0	reference state

defined as the ratio of the utilized thermal energy load by consumers to the rated output power of the wells, circulation, pumps, etc. The collected data are quantified and illustrated in tables show different actual average ambient temperatures for comparison purposes. According to the monitoring studies between 2006 and 2008 years, yearly average maximum thermal energy production from wells are found to be 50 MW. According to these results, geothermal energy provides economical district heating facility.

2. Salihli GDHS description

The Salihli geothermal field is about 7 km from the town Salihli (about 55 km far from the city Manisa, located in the western part of Turkey). It has a maximal yield of 0.175 m^3/s at an average reservoir temperature of 86 °C. The Salihli GDHS was initially designed for a capacity to cover 20,000 residences equivalence. Of these, 5470 residences equivalence are heated by geothermal energy as of December 2006. The outdoor and indoor design temperatures for the system are 4 °C and 22 °C, respectively. Modeled system of main cycles where hospitals, greenhouse, and official buildings heated by geothermal energy were also included. At the beginning of 2007, there were 14 wells ranging in depth from 40 to 513 m in the Salihli GDHS. Of these, 6 wells were in operation at the date studied. Seven wells (designated as K2, K5, K11, K12, K15, K18, and K19) are production, greenhouse and balneology wells. Seven wells (designated as K1, K3, K4, K7, K9, K16 and K17) in the system are reinjection wells. The primary thermal water is reinjected into the well(s) and discharged via natural direct discharge after extracting its enthalpy, while the secondary fluid (i.e., clean hot water) is utilized to heat the buildings through the substation heat exchangers. The well head temperatures of the production wells vary from 62 to 99 °C, while the volumetric flow rates of the wells range from 36 to 576 m^3/h. Geothermal fluid is sent to the primary plate type heat exchanger (between the geothermal fluid and the district heating water) and is cooled to about 38–42 °C, as its heat is transferred to the district heating water.

The geothermal fluid is discharged via natural direct discharge and reinjected (reinjection studies are expected to be completed in the near future). The temperatures obtained during the operation of the Salihli GDHS are, on average, 86–88/38–42 °C for the district heating distribution network and 56–57/40–42 °C for the building circuit. By using the control valves for flow rate and temperature at the building main station, the needed amount of water is sent to each housing unit and the heat balance of the system is achieved. Geothermal fluid collected from the production wells at an average well heat temperature of about 86 °C, is pumped to the inlet of the heat exchanger mixing tank, a main collector (from four production wells) with a total mass flow rate of about 175 kg/s [3,4]. Fig. 1 illustrates an experimental measurement on thermal water production and energy distribution pipe lines by using ultrasonic flow meter.

3. Analysis

Coefficient of performance (COP) analysis, as described in this paper and in more detail in a series of author's recent energetic, exergetic and exergoeconomic studies by [5–19], has been applied to the performance evaluation of GDHSs, earth to air heat exchangers, and thermal systems [e.g., 5–21]. The balance equations (mass, energy and exergy flows in the system and its components) are considered for steady-state steady-flow control volume systems, and the appropriate energy and exergy equations are derived for this system and its components [6,7]. The heat losses from the distribution networks/pipelines were specifically considered in the analysis due to fact that their indirect effects through temperature drops were part of the calculations. However, the pressure drops in the distribution networks/pipelines were also considered negligible.

The balance equation for the mass flow rate of the overall Salihli GDHS can be expressed as:

$$\sum_{i=1}^{n} \dot{m}_{w,i,\mathrm{Tot}} - \dot{m}_r - \dot{m}_d = 0 \tag{1}$$

The total energy input to the GDHSs may be calculated from the following equations, respectively:

$$\dot{E}_{\mathrm{brine}} = \dot{m}_w (h_{\mathrm{brine}} - h_0) \cong \sum_{i=1}^{n=5} \dot{m}_{w,i} (h_i - h_0) \tag{2}$$

The energy efficiency of the GDHSs can be defined as the ratio of total energy output to total energy input as follows:

$$\eta_{\mathrm{sys}} = \frac{\sum_{i=l}^{n=k} \dot{E}_{\mathrm{useful,HE},i}}{\dot{E}_{\mathrm{brine}}} \tag{3}$$

where in most cases "output" means "useful".

COP value it means that system coefficient of performance ($\mathrm{COP_{sys}}$) is defined as the ratio of the useful energy rate ($\dot{E}_{\mathrm{useful}}$) (consumed energy rate by consumers) to the rated output power of the well pumps, circulating pumps, and pump of pressurized water tank. $\mathrm{COP_{sys}}$ can be defined as follows, respectively:

$$\begin{aligned} \mathrm{COP_{sys}} &= \frac{\dot{E}_{\mathrm{useful}}}{\dot{W}_{\text{well pump(s)}} + \dot{W}_{\text{circulating pump(s)}} + \dot{W}_{\text{booster pump(s)}} + \dot{W}_{\text{pump(s) of pressurized tank}}} \\ &= \frac{\dot{E}_{\mathrm{brine}} \eta_{\mathrm{sys}}}{\sum \dot{W}_{\mathrm{Tot}}} \end{aligned} \tag{4}$$

4. Results and discussion

The project entitled Monitoring of Performance of the Salihli Geothermal District Heating System was realized between September 1, 2006 and September 1, 2008. This project aims to perform exergoeconomic analysis of the system which is basically a combination of exergy and economics for long term operational conditions. In analysis, effect of change in ambient temperature on each component of the system and exergy efficiency of the whole

(a) A heat exchanger view at Salihli GDHS main energy distrubition station

(b) An experimental measurement and monitoring studies on thermal water production and energy distribution pipe lines by using ultrasonic flow meter.

Fig. 1. Various views of the appearances of the Salihli GDHS.

system was evaluated for 2006–2007 and 2007–2008 heating seasons operating and ambient temperature data. In the performance evaluation, parametric studies were conducted to investigate how varying reference temperature influence the energy and exergy efficiencies of the system and developed practical correlations for efficiency predictions after re-injection studies. During this investigation, information on the energetic, exergetic efficiencies, and exergoeconomic parameters of the GDHS was collected for two years.

In the present study, the results obtained from the monitoring studies were evaluated to determine the overall COP value of Salihli GDHS. Average energy efficieny of Salihli GDHS was found to be 58%, 59% for 2006–2007 and 2007–2008 heating seasons, respectively. In parallel with, maximum thermal energy production rate was reached 46.8 and 51.1 MW in December 2006 and December 2007. In addition maximum thermal water production mass flow rate was realized as 148.8 kg/s and 157.45 kg/s in same months. Figs. 2–5 show that monthly average enthalpy value of produced thermal water and re-injected thermal water for monitoring heating seasons. Monthly variations of the produced thermal energy rates, utilized net energy rates from wells can be read from Figs. 6 and 7 and Table 1. It is expected that on cold months, energy production rates was increased from 10 MW to 50 MW. Additionally, useful energy rates were found to be between 10.9 and 28.9 W. On the other hand, maximum energetic and exergetic efficiencies were monitored in March 2007 and March 2008. According to our geothermal field studies and collected, measured real operating data, and ambient temperatures; calculated average yearly energetic and exergetic efficiencies were found to be 58.9%, 69.5%, respectively. In the following Table 1, author list the selected thermal data related to system that is used in the calculations to obtain COP, energy and exergy efficiencies.

Some exergetic, energetic and thermodynamics analysis yearly average data provided for one representative unit of the Salihli

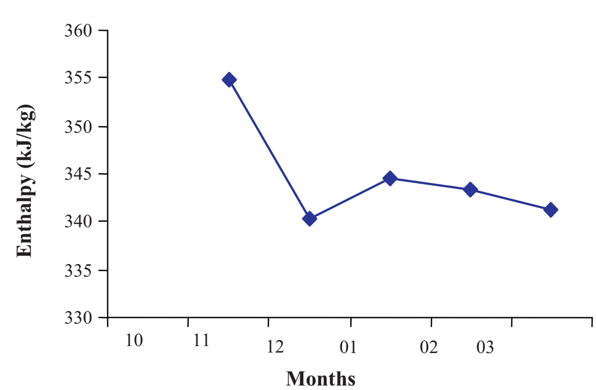

Fig. 2. Monthly average enthalpy value of produced thermal water in 2006/2007 heating season.

Table 1
Some exergetic, energetic and thermodynamics analysis yearly average data provided for one representative unit of the Salihli GDHS in 2006/2007 and 2007/2008 heating seasons.

Months	Energy efficiency (%)	Exergy efficiency (%)	Monthly average thermal energy rate production (MW)	Monthly average exergy rate production (MW)	Monthly average ambient temperature (°C)	COP_{sys}
2006/2007 Heating season						
November	59	70	41.3	4.7	9.1	104.6
December	57	66	44.4	5.0	6.9	108.7
January	57	67	46.8	5.3	7.1	114.6
February	58	69	45.4	5.4	8.6	113.1
March	61	74	38.3	4.0	11.8	100.3
Average	58	69	43.2	4.9	8.7	108.3
2007/2008 Heating season						
October	66	86	16.6	1.6	18.5	47.1
November	60	74	38.3	4.3	11.6	100.0
December	56	65	51.1	6.2	5.7	124.4
January	55	61	47.8	5.1	3.5	113.4
February	57	66	45.4	5.1	6.8	112.1
March	62	78	36.3	3.6	14.2	97.9
Average	59	72	39.2	4.2	10.05	99.2

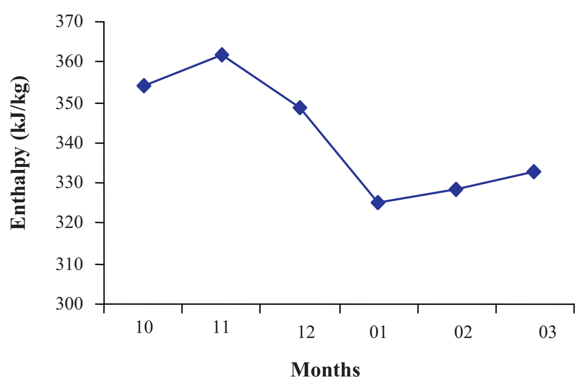

Fig. 3. Monthly average enthalpy value of produced thermal water in 2007/2008 heating season.

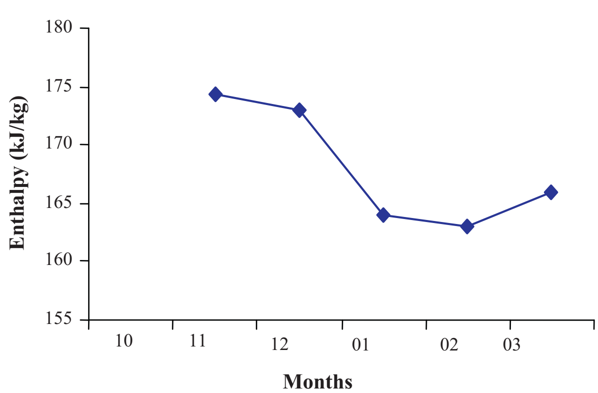

Fig. 4. Monthly average enthalpy value of re-injected thermal water in 2006/2007 heating season.

GDHS in 2006/2007 and 2007/2008 heating seasons were given in Table 2. It can be seen that restricted dead state was taken to be the state of environment. It is obvious from the table that the highest exergy efficiency occurs in October 2007. Besides, total exergy efficieny losses values are obtained to be from 14% to 39% for the system. Table 2 shows the energy and exergy analysis results of the system. In addition, calculated average reference temperatures, energy and exergy production rate value is given in Table 1. Utilized pump rates are also calculated for each state, and are listed in

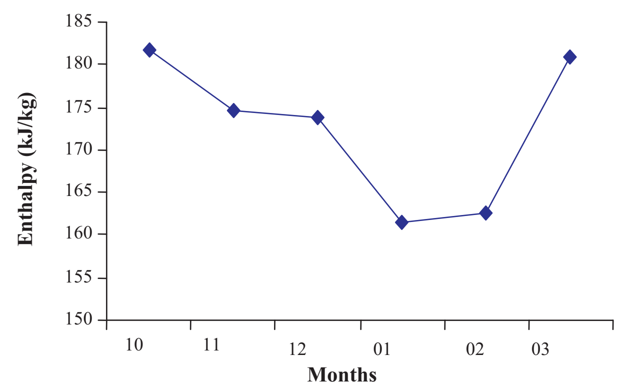

Fig. 5. Monthly average enthalpy value of re-injected thermal water in 2007/2008 heating season.

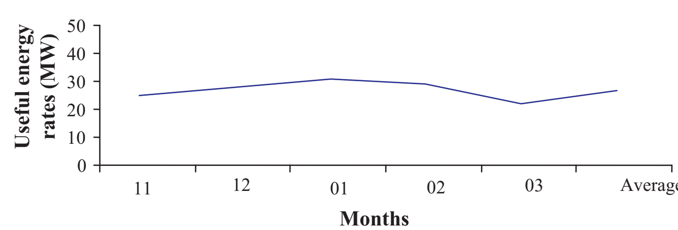

Fig. 6. Distribution of monthly average useful energy rates in 2006/2007 heating season.

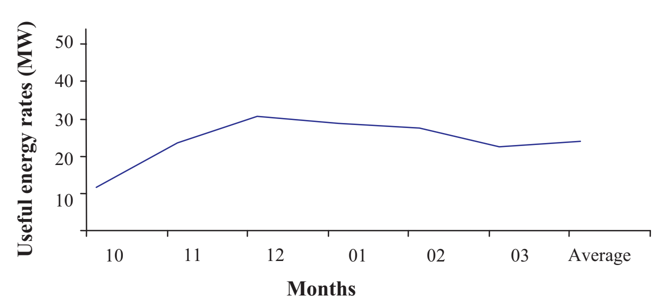

Fig. 7. Distribution of monthly average useful energy rates in 2007/2008 heating season.

Table 2
Utilized pump power of the Salihli GDHS in 2007/2008 heating season.

Component	Utilized power (kW)
Well pumps	65.25
Salihli booster pumps	55
Salihli circulation pumps	112.5
Total	232.75

Table 2. In this study, the restricted dead state was taken to be the state of environment.

COP values are evaluated in terms of the system by using Eq. (4). The results show that system coefficient of performance (COP_{sys}) changes between 47.1 and 124.4. The highest highest COP_{sys} value in 2006/2007 heating season occurred in January and February, yet the highest COP_{sys} value occurred in 2007/2008 heating season occurred in December. In addition, yearly average heating COP_{sys} value was found to be 99.2 and 108.3, respectively.

5. Conclusions

In this study, coefficient of performance, energetic and exergetic losses has been investigated. The results were given and discussed. The monitoring results clearly indicate that the geothermal district heating applications not only provide economical energy savings but also have absolute environmental advantages. In Turkey, among the high energy consumptions load for heating comes in the first place, yet geothermal energy is not benefited enough evens the geographical location is proper for this.

The main conclusions that may be drawn from the present study are listed below:

1. Geothermal district heating investments should be encouraged in Turkey. For this aim requires an intensive and legislative effort.
2. Monitoring studies should be extended long term for defining more realistic geothermal energy utilization of the site and suitable technical equipment selection and reservoir management.
3. If a geothermal district heating system has artesian well(s) it is expected that COP_{sys} value can reach higher value.
4. Undertaking monitoring study should be become widespread in Turkey.

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